AN ANALYSIS OF BIOGAS PRODUCTION FROM GRASS SILAGE AS DEPENDENT UPON FEED QUALITY

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Abstract. The purpose of the study is to verify whether the scrupulous observance of grass silage quality required for high production dairy cow feed is necessary for input substrate. Given that bacteria do not work as intensely as the ciliates in the rumen of cows, this goal is not required; however, it is desirable. Cows may thus provide a suitable model for showing us a possible direction that may be followed in biogas research over the next few years. If a dairy cow weighing 600 kg receives 20 kg TS per day and the capacity of the digestive tract is 180 litres, then the digestive 'fermenter' load will be 111 kg oTS per m3 per day. If these parameters are assessed in terms of the current construction of biogas plants, then what we are talking about is loading the fermenter with 5 kg oTS per m3 per day. Some of the biogas plants under study, such as Kouty, for example, are currently at 7,5 kg oTS/m^3/day. In Germany, the research team operated a biogas plant continuously with a load of 12 kg oTS/m3/day and, at the same time, conducted experiments in loading 20 kg oTS/m^3/day.

Key words: grass silage, fermentation, biogas, biogas plant

Introduction

The Czech Republic is currently experiencing a significant development regarding biogas plants. The number of newly launched biogas power plants is estimated to exceed 40 000 units per year. As far as agricultural biogas production is concerned, the power plants use manure and corn as the primary substrates. Owing to falling livestock numbers, unused areas of permanent grassland are increasing, while manure production is decreasing. This study thus looks at the use of a hitherto overlooked substrate, namely grass silage for use by means of anaerobic fermentation.

The area of permanent grassland in the Czech Republic arises from the morphology of the country's 980000 hectares. In addition to the border mountains, there is also –a substantial area known as Českomoravská vysočina (the Czech-Moravian Highlands). Most of the land is very extensively farmed, particularly as a result of the European Union's subsidy policy. Assuming an increase in the production of a composition of grass species as biomass, which will be obtained by replacing the current, intense and powerful hybrid, while nutrition will be ensured in terms of nitrogen, phosphorus and potassium by distributing the digestate, it would be possible to produce the quantities of biomass necessary to ensure the production, by means of biogas, of approximately 2800 GWh of electric energy per year, in other words, 3.5% of the Czech Republic's total annual electricity production.

The production of biogas

Biogas is a product of the bacteria metabolism that breaks complex organic compounds down into simpler substances. The end product of this breakdown is a mixture of gases with a predominance of methane CH_4, carbon dioxide CO_2, hydrogen sulphide H_2S, ammonia NH_3, water vapour H_2O, hydrogen H_2 and oxygen O_2. In 1986, Nordberg described the anaerobic fermentation process as consisting of four stages. Hydrolysis leads to the breakdown of high-molecular compounds, namely proteins, carbohydrates, fats and cellulose, using enzymes to lower the weight of molecular substances such as simple sugars, fatty acids, amino acids and water. Acidogenesis is a more complex processing of fatty acids. Facultative aerobic bacteria consume the last remains of oxygen, creating the strictly anaerobic conditions required for methanogenesis. During this process, the pH decreases, in other words, the environment is acidified. This leads to the production of higher fatty acids Cx-C3 to the level of propionic acid, as well as to the production of simple alcohols, namely ethanol CH_3OH and, especially, of carbon dioxide, hydrogen, ammonia and hydrogen sulfide. Acetogenesis is a production process for C2 acetic acid CH_3 COOH, carbon dioxide CO_2 and hydrogen H_2. The hallmark of acetogenesis is the sensitivity of bacteria to temperature changes.

Metanogenesis is the process by which methane CH_4, carbon dioxide CO_2 and water are produced [Straka et al., 2003].

Materials and methods

Parameters of feed quality grass silage

The quantified quality parameters for silage are: total solids, organic total solids, macro components, namely Ca, P, Na, K and Mg, ash, crude protein, digestible crude protein, fibre, acid-detergent fibre, neutral-detergent fibre, lactic acid, acetic acid, butyric acid, the mg KOH acidity of the leachate water, pH, total energy, metabolizable energy, net lactate energy, net energy of fattening, starchy food value, and the silage's own production of methane, measured in cubic meters under normal pressure and temperature conditions per kg of organic dry substance.

The methodology for biogas production determination

The biogas production was measured in accordance with Directive VDI 4630: Fermentation of organic substances, characteristics of substrates, sampling, data definitions of substrates and fermentation tests (VDI 4630:Vergärung organicher Stoff, Substratcharakterisierung, Probenahme, Stoffdatenerhebung, Gärversuche). The experiments were performed at 38°C and three samples of each substrate were tested. The resulting output was defined as the average of those three results. The average test substrate quantity was 20 g, the quantity of vaccination sludge was 300 g and the total solids, 4%. The ammonia nitrogen content was less than 800 mg·kg^{-1} of vaccination sludge. The test was carried out over a period of twenty-one days. A fermentation test was carried out on the vaccination sludge of a silage in parallel in order to determine the substrate's biogas production.

To obtain accurate results, the biogas production was calculated on the basis of the volume (m^3) of methane under normal pressure and temperature conditions, at 0°C, 1,01325 x10^5 Pa, and the production was related to the organic dry substance.

Results

Given that twenty-five separate dependencies were subject to scrutiny, the written study has been divided into two articles. This one focuses on feed quality and the other is entitled "An analysis of biogas production from grass silage, in respect of the quality for use in biogas power plants".

The first dependency to be investigated was that of methane production on the lactic acid content in grass silage.

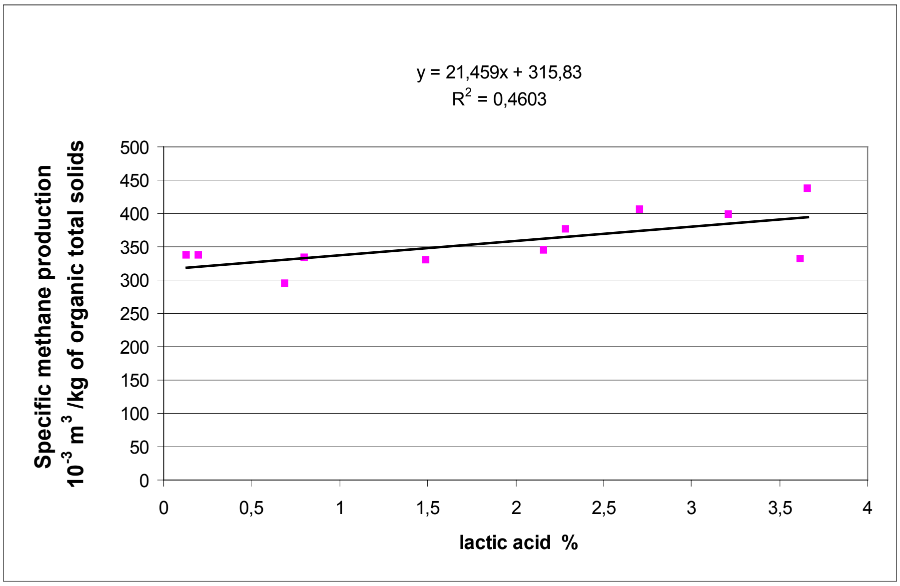

Fig. 1. Dependence of methane production on the lactic acid content in grass silage

The concentration of lactic acid proved to be a sensitive parameter. The dependence is very obvious and the increase in lactic acid is in direct proportion to the increase of methane production. The differences in concentrations varied widely between samples (Vraclav), ranging from 0.13% in total solids (TS), with a methane production of 337.35 ·10^{-3} m^3·kg^{-1} of organic total solids (oTS) to 3.66% in TS, with a methane production of 436.23·10^{-3} m^3·kg^{-1} oTS. The sample with the lowest methane production, at

$293.86 \cdot 10^{-3}$ $m^3 \cdot kg^{-1}$ of organic total solids, shows a very low concentration of lactic acid, at 0.69%, in the total solids.

The determination coefficient (value of reliability – R^2) reached a value of 0.4603. The regression line takes the form of y=21.459x+315.83. Parameter β1, the slope of the straight line, is 21.459 and is therefore positive, has the shape of a rising line. Parameter β0 is 315.83. To review the overall suitability of the model, the F-test was used to test it as a whole. This will determine whether the p-value is less than 0.05, the chosen level of significance.

F=7.67

p-value = 0.022

It is true that the p-value <0.05 (with a confidence level of 95%)

In terms of statistics, the model is significant (conclusive) and demonstrates the correlation between increased lactic acid content and increased methane production.

Another dependence was that of methane production to the mg KOH acidity of the water leachate in grass silage.

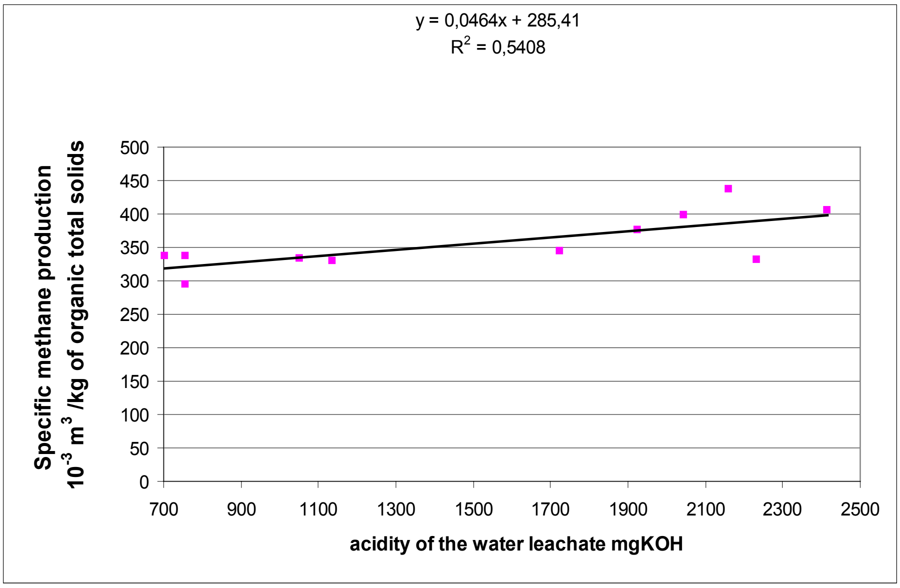

Fig. 2. Dependence of methane production on the mg KOH acidity of the water leachate in grass silage

The parameter of water extraction acidity also demonstrates a sensitive reaction in terms of the relationship between the increase in acidic concentration and an increase in methane production. The lowest value, at 702 mg KOH, was found in a sample from Věžovate Plane and the highest, at 2415 mg of KOH, in a sample from Dolni Dobrouč. The samples from Kunčina, which showed the lowest production of methane, , at $29.,86 \cdot 10^{-3}$ $m^3 \cdot kg^{-1}$ oTS, had the second lowest water leachate mg KOH acidity, with a value of 755 mg KOH. At the same time, the sample from Kouty, with a production rate of $436{,}23 \cdot 10^{-3}$ $m^3 \cdot kg^{-1}$ of organic substance, had the second highest water leachate mg KOH acidity, with a value of 2160 mg of KOH.

The determination coefficient (value of reliability – R^2) reached a value of 0.540757. The regression line takes the form of y=0.046x+285.414. Parameter β1, the slope of the straight line, is 0.0463 and is therefore positive and has a shape of a rising line. Parameter β_0 is 285.4144.

To review the overall suitability of the model, the F-test is used to test it as a whole. This will determine whether the p-value is less than 0.05, the chosen level of significance.

F= 10.59746913

p-value = 0.009911771

It is true that p-value <0.05 (with a confidence level of 95%)

In terms of statistics, the model is significant (conclusive) and demonstrates the correlation between increased lactic acid content and increased methane production.

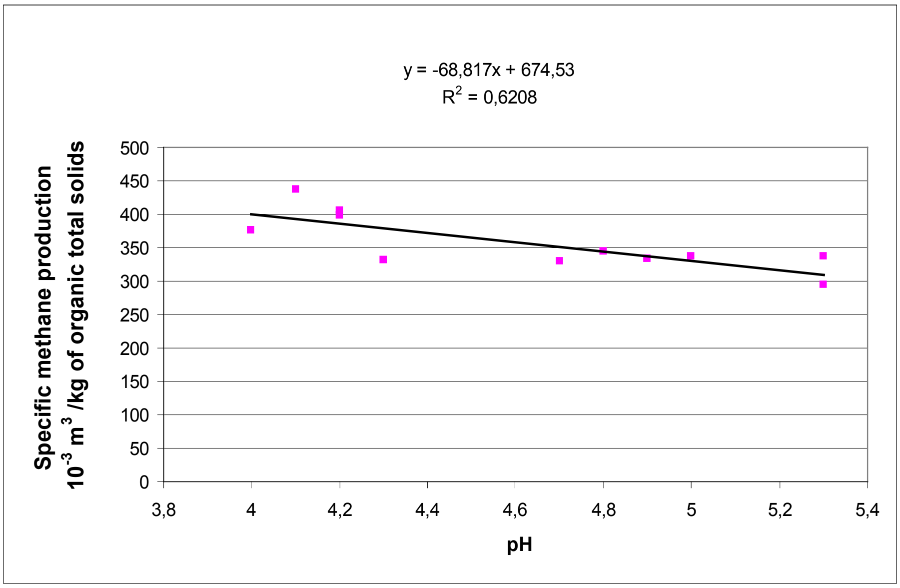

Fig. 3. Dependence of methane production to grass silage pH value

The pH value of silage is one of the most easily identifiable parameters. The pH value of the samples examined ranged between 4.00 and 5.30. It can be seen that the more acidic the sample, the higher the production of methane. The methane production from Kunčina was $293.86 \cdot 10^{-3}$ $m^3 \cdot kg^{-1}$ of organic substance and the sample had the lowest acidity, at a pH of 5.30. In contrast, the sample from Kouty, where the methane production was $436.23 \cdot 10^{-3}$ $m^3 \cdot kg^{-1}$ of organic substance, had a pH value of 4.00.

The determination coefficient (value of reliability – R^2) reached a value of 0.620764. The regression line takes the form of y=- 68.817+674.526x (Fig.3). Parameter β_1, the slope of straight line, is 68.817 and is therefore negative and has a shape of a falling line. Parameter β_0 is 674.52616.

To review the overall suitability of the model, the F-test is used to test it as a whole. This will determine whether the p-value is less than 0.05, the chosen level of significance.

F= 10.59746913

p-value = 0.009911771

It is true that p-value <0,05 (with a confidence level of 95%)

In terms of statistics, the model is significant (conclusive) and demonstrates the correlation between increased lactic acid content and increased methane production.

To review the overall suitability of the model, the F-test is used to test it as a whole. This will determine whether the p-value is less than 0.05, the chosen level of significance.

F= 14,73196721

p-value = 0,003977321

It is true that p-value <0.05 (with a confidence level of 95%)

In terms of statistics, the model is significant (conclusive) and demonstrates the correlation between increased pH and increased methane production.

Conclusions

The study evaluated eleven samples of grass silage with differing levels of feed quality. One sample was of excellent quality, the quality of four samples was successful, that of three was less successful, though still usable as animal feed, two samples were unsuccessful, but conditionally usable for feeding, and one sample failed to meet the quality criteria and was deemed unsanitary. However, in respect of biogas production, even the use of the low-grade samples is substantiated.

Only four of the parameters taken into consideration were statistically significant. The first was the energy parameter, which is to say, lactic acid. At the lactic acid level, the energy contained in the simple sugars produced by photosynthesis in the grass stabilizes. Monosaccharides, in other words, the lactic fermentation product produced by lactic acid, are the major carriers of energy in the grass mass. Therefore, lactic acid content is crucial to methane production, something which was also confirmed with statistical analysis and by the result of the confirmed statistical significance.

Two of the other parameters, namely the pH-value and acidity of water extract, define the long-term biological stability of grass silage. These parameters can be partially described as equivalents, or as parameters operating in direct proportion to each other. This is characterized by the results, which confirm that a reduction in the biological stability of grass silage gives rise to a significant decrease in methane production. When grass silage has a long-term stability, then a higher methane (biogas) production can be expected.

The last statistically significant parameter was that of grass silage total solids. This parameter is logical, because solids hold all the energy in the form of sugars, which is to say, mono-, di- and polysaccharides to the cellulose and hemicellulose levels, as well as fats and proteins. Therefore, in terms of grass silage production profitability, it is necessary to maximize the yield of solids per hectare of grassland, since the total solids yield is in direct proportion to biogas and methane production, respectively. In the future, this will primarily mean increasing the yield of grass mass per hectare by means of the application of intensive hybrid grass varieties in renewed forms of permanent grassland. Intensification will most certainly include the production of annual rye grass and multiannual fodder plants grown on arable land. This, in turn, entails not only the choice of a suitable variety, but also, an in particular, intensive nutrition that includes both nitrogen and other nutrients, something which could largely be ensured by delivering the digestate back to the grassland. The nutrient content in one ton of digestate is approximately 4.5 kg of nitrogen, of which 3-3.5 kg takes the form of ammonia, as well as 2 kg of phosphorus and 4 kg of potassium. These values demonstrate the fact that the use of digestate should ensure the nutrition of grasslands.

Although other parameters showed a certain dependence, such as energy parameters, namely the total energy and metabolizable energy, than clean lactation energy and clean fattening energy as statistically significant were not evaluated. Methane production quantities displayed some sensitivity to acetic acid concentration; however, it was not possible to produce statistical confirmation of this dependence. The same applies to the BNVL parameter; there was a response, though it was not statistically confirmed. The protein content, be it was crude protein, digestible crude protein, PDIA, PDIE or PDIN, had no significant influence on methane production and the dependence between the production values and those of these parameters was not confirmed.

No direct correlation was found between methane production and the content of macroelements such as calcium, sodium, phosphorus, magnesium and potassium.

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ANALIZA ZALEŻNOŚCI MIĘDZY PRODUKCJĄ BIOGAZU A JAKOŚCIĄ KISZONKI PRZEZNACZONEJ NA PASZĘ DLA ZWIERZĄT

Streszczenie. Celem pracy jest ustalenie, czy konieczne jest dokładne przestrzeganie jakości kiszonki z traw dla substratu wsadowego tak jak jest to w przypadku paszy dla krów mlecznych o wysokiej wydajności. Zakładając, że bakterie nie działają tak intensywnie jak w przypadku orzęsków żwacza, osiągnięcie powyższego celu nie jest wymagane lecz pożądane. Zatem krowy mogą stanowić odpowiedni model ukazujący możliwy kierunek badań nad biogazem na najbliższych kilka lat. Jeśli krowa mleczna ważąca 600 kg otrzymuje 20 kg TS na dzień a możliwości układu trawiennego wynoszą 180 litrów, to obciążenie układu trawiennego będzie wynosiło 111 kg TS na m^3 dziennie. Jeżeli powyższe parametry dotyczą biogazowni to obciążenie zbiornika fermentacyjnego będzie wynosiło 5 kg TS/m3/dzień. Niektóre biogazownie, np. Kouty obecnie stosują 7.5 kg obciążenie/m3/dzień. W Niemczech grupa badawcza obsługiwała biogazownie przy stałym obciążeniu 12 kg TS/m3/dzień i jednocześnie przeprowadzała badania przy obciążeniu 20 kg TS/m3/dzień.

Słowa kluczowe: kiszona z traw, fermentacja, biogaz, biogazownia

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